LIGHTWEIGHT EMBANKMENT FOR DIFFERENTIAL SETTLEMENT REDUCTION ON HIGHWAY BRIDGE APPROACH

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ABSTRACT

A major problem occurring to structures constructed on soft marine deposit is excessive settlement especially on highway embankment and highway's bridge approaches, which are supported by different types of foundations. Using different types of foundations to support highway structures on thick and highly compressible soft clay especially in Bangkok and its vicinity usually results in differential settlement between bridge superstructures and highway embankments reducing driving comfort and safety of traveling public. Use of lightweight material is an alternative approach to reduce the vertical pressure exerting to the soft subsoil. Recently, Department of Highways, Thailand has initiated an innovative project to apply the lightweight soil technology to reduce the excessive settlement at bridge approach. The lightweight embankment, comprising local soft clay, Portland cement and air foam, was constructed on highway route number 35, at the kilometer post of 72+712.5 to 72+775.0. Geotechnical instruments were installed at the tested site to monitor its behavior for both during constructing and during its operating periods. Settlement data showed that the lightweight embankment reduces the differential settlement at the tested bridge approach comparing to conventionally constructed bridge approach.

1. INTRODUCTION

Construction of highway structures on soft marine clay always encounters instability and excessive settlement problems due to its unsuitable properties of low strength and high compressibility. In highways' construction techniques, the problem is underlined for bridge approach, the section connecting bridge structure and embankment. A bridge is normally supported by deep foundation, while the pavement is constructed on compacted base material overlying the subgrade. The occurring pressure due to traffic and structure loads is then transferred to different depths of the underlining subsoil. At different subsoil depths, the ability to support load and rate of consolidation are also varied thus causing differential settlement at the bridge approach. The dip of the highway surface at the joint connection between the bridge approach and highway embankment reduces driving comfort and may cause injury and deadly accident if the vehicle loses control.

Recently, Thailand's Department of Highways (DOH) has initiated a program to improve the methods of design, construction and remediation the bridge approach using lightweight embankment material of air foam stabilized soil (AMS) to reduce vertical settlement. The research project was a collaboration of DOH and Public Work Research Institute of Japan (PWRI) who gave supports for mixing plant and technical expertise. The detail of the research program is presented elsewhere. [1]

The past application of AMS was first implemented in Japan. The AMS embankment was constructed with the dimension of 7 m in height and 22 m by 22 m in length and width. After a year of construction, the vertical settlement was reported to be 29 mm, which was minimal when compared to the settlement of the conventionally constructed embankment (approximately 125 mm) [2]. Another trial embankment was constructed at the Ladkrabang interchange of Bangkok-Chonburi motorway, Thailand with the dimension of 4 m in height and 14 m by 14 m in length and width. The study found that the settlement of the light weight embankment was reduced dramatically. The settlement at the center line of the embankment of 0.06 m was recorded after 49 days of construction compared to that of 0.1 m taken from the analysis on conventional embankment. [3]

This paper presents the application of AMS as lightweight highway embankment at the bridge approach underlain by soft Bangkok clay. The tested highway embankment was constructed on highway route number 35, at the kilometer post of 72+712.5 to 72+775.0. Results of the study shows that the use of AMS can reduce differential settlement thus reduction of the risk to accident and long term maintenance cost. The use of AMS also promotes effective use of local material and reduction of highway structure destruction due to hauling of construction materials. Geotechnical instruments were installed at the site to monitor the embankment behavior. The discussion of construction techniques of the AMS is also presented in this paper.

2. PROPERTIES OF THE BANGKOK CLAY

Bangkok clay has high water content possessing very low shear strength and high compressibility. It is normally encountered in the central plain of Thailand around Bangkok and its vicinity. The soft material stratum varies from 4-5 m to more than 20 m in thickness. The much thicker Bangkok clay layer is usually found close to the shoreline. Figure 1 shows typical cross-section of marine clay deposited in the Choa Phraya river basin, central plain of Thailand. Bangkok clay is normally consolidated or slightly consolidated marine clay depending upon where the clay is found [5]. The presence of Bangkok clay at construction sites affects project operation costs, which include design, planning, construction, and maintenance cost. Also, the structural behavior in short and long terms is also affected by its presence and should be highly considered.

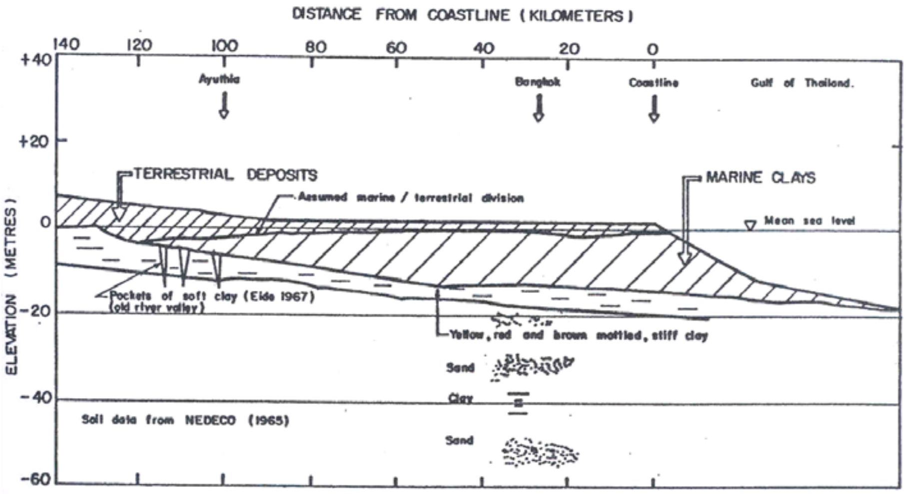


Figure 1. Typical cross-section of soft clay deposited in Choa Phraya river basin. [4]

3. AIR FOAM STABILIZED SOIL (AMS)

AMS is a type of light weight materials having high compressive strength, low compressibility and low permeability. The strength of the AMS depends on the amount of mixed cement and air foam added. The process of manufacturing AMS can be described as follows. Firstly, soft clay is thoroughly mixed with water until it becomes slurry. Typically, the amount of water added is approximately triple amount of the liquid limit. It is then pumped into a mixing chamber to mix with Portland cement type 1. The next step is to mix the product obtained from the first step with the prepared air foam. The air foam can be generated by mixing chemical foaming agents (Polyfoam-200A, non-toxic organic polymer) with water. The prepared solution is fed through a nozzle under high pressure forming air foam. The density of the AMS depends on the amount of added foam. The prepared material will be pumped to the prepared formwork at the construction site. After installation of AMS is completed, curing process starts. The shear strength of the AMS increases with curing time. The standard properties of in-situ clay used for the mixture and AMS are shown in Table 1.

Table 1. Typical properties of AMS and in-situ clay from the site.

Properties	Air Foam Stabilized Soil	In-situ Clay
Density (kg/m^3)	600-1,200	1,560
Water Content (%)	-	82
Liquid Limit (%)	-	96
Plasticity Index	-	55
Unc.Compressive Strength (ksc)	1-10	-
Flow (mm)	160-200	-
Permeability (mm/s)	1×10^{-4}-1×10^{-5}	-

3.1 Mixing Process of AMS

The mix design of the AMS was referenced and adapted from a technology manual of the foam mixing stabilized method. [6] The unit weight of the air foam stabilized mix was required at 1,000 kg/m^3. According to JHS A313 test standards, the flowing ability was recommended at 180 mm. In addition, the unconfined compressive strength of the sample at 28 day curing was 6 ksc, about 1.5 times of the required strength of 4 ksc, which is equivalent to the CBR value of 10%. According to the preliminary setup value, the different amounts of Portland cement in the mixture were tested to identify optimal quantity of Portland cement in laboratory.

The AMS consists of three components including soil slurry, Portland cement, and air foam. Slurry can be prepared by adding water to about three times of the liquid limit in order to increase its flowing ability to approximately 450 mm. Portland cement is then mixed with the slurry to increase strength of the AMS. At the same time, air foam was also prepared. The optimal mixture ratio between foaming agent and water was 1:19 and they were mixed thoroughly in air foam mixing device with careful control of the water and air pressure in order to get homogeneous air foam mixture. The density of air foam was controlled at 50 kg/m^3.

The mixing process started with thoroughly mixing soil slurry and Portland cement using hand mixer, and later mixed the solution with air foam. Then, the material was mixed thoroughly by hand until a homogeneous solution was achieved. The density of the air foam mixed solution and flowing ability were then checked, and the air foam mixed solution was poured into molds and covered with a plastic sheet for strength tests. The density and flowing ability obtained from different cement contents are shown in Table 2.

Table 2. Density and flowing ability of the AMS samples.

Mix No.	1	2	3	4
Cement Content (kg/m^3)	150	175	200	250
Moisture Content (%)	288	312	288	312
Density (kg/m^3)	1,026	1,024	1,004	967
Flow Value (mm)	145	165	160	190

3.2 Unconfined Compression Tests of AMS Samples

The unconfined compressive strength was tested on the prepared samples. The sample was extruded from the mold and the size of the tested sample was trimmed to 50 mm in diameter and 100 mm in height. Figure 2 shows the results of unconfined compressive strength of the tested samples at different curing time. According to the design, the unconfined compressive strength of the prepared sample should be at least 6 ksc at 28 days of curing time. Based on the relationship shown in Figure 2, the amount of Portland cement of 218 kg/m^3 can be determined. This amount of Portland cement was used for plant mixing at the construction site.

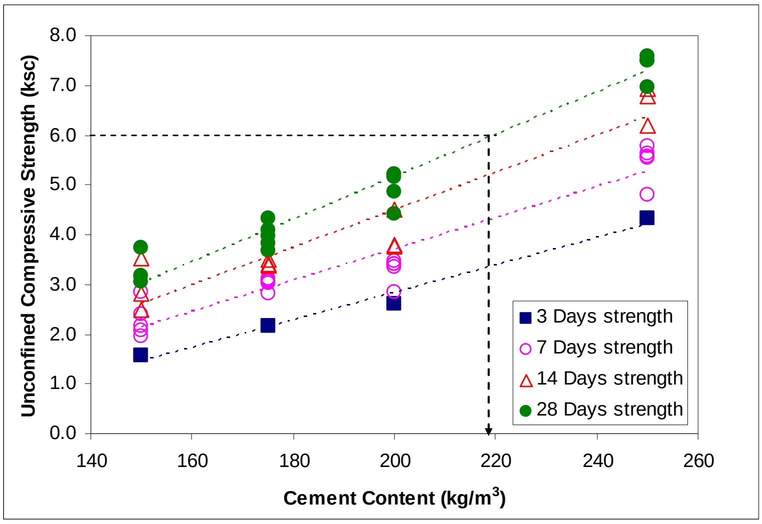


Figure 2. Unconfined compressive strength of AMS.

4. APPLICATION OF AMS AT THE BRIDGE APPROACH

The application of AMS was implemented at a bridge approach of a bridge crossing over Khlong Donchan in Samutsongkram province approximately 70 km west of Bangkok. The site was located on the inbound lane on highway no. 35 at the kilometer post of 72+712.5 to 72+775.0. The total amount of AMS used in the construction was estimated to be 1,600 m^3 and this amount was allocated to be 550 and 1,050 m^3 for use in the first and second construction phase, respectively. In each phase, the embankment was constructed in 3 layers. The thickness of each layer was 0.5 m in height. The AMS was cast- in-place divided into blocks. The typical drawing for construction is shown in Figure 3.

The unconfined compression test of the on-site mix was carried out for quality control of the strength of the AMS. At 28 days, the unconfined compressive strength of the sample collected from both construction phases were all greater than 4 ksc. The unit weight of the tested sample was ranged within 1,000±70 kg/m^3 as shown in Figure 4.

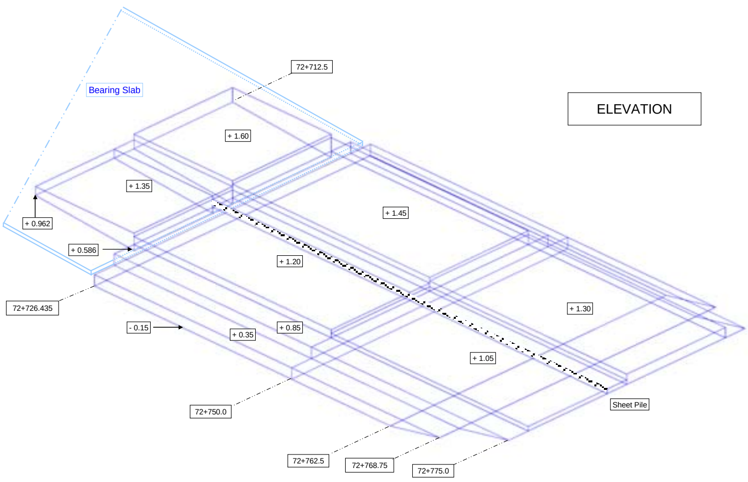


Figure 3. Elevation of air foam stabilized embankment.

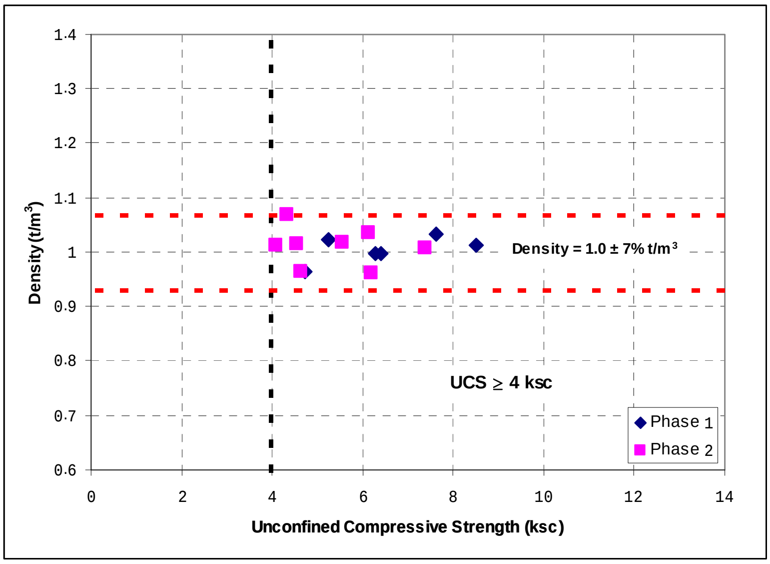


Figure 4. Unconfined compressive strength of collected samples.

5. AMS EMBANKMENT MONITORING

Geotechnical instruments were installed at the construction site for short and long term performance of the constructed embankment. The types of geotechnical instrumentation and installed locations are shown in Figure 5. The data was recorded periodically (once a week during construction, and once a month after construction). Figures 6-8 shows data obtained from the installed inclinometers and settlement cells, respectively.

As shown in Figures 6a) and 6b), the vertical inclinometer IN-1 showed horizontal movement inwards to the excavation area. Movement in the a-axis mostly occurred after completion of excavation. The horizontal movement was approximately 6 mm at the depth of 4 m below the top of the inclinometer. This movement decreased after completion of the embankment construction. Currently, at the same location, the movement of approximately 3 mm was recorded. In b-axis, slightly and insignificant horizontal movement was detected. The horizontal movement occurring in the a-axis of another vertical inclinometer IN-2 was greater than that of IN-1, see Figure 6c) and 6d). The maximum horizontal movement of 15 mm outwards from the embankment was recorded at the depth of approximately 4 m from the top of the inclinometer. The movement mostly occurred after completion of the first phase. This may be the result of the traffic load applied close to the inclinometer location. In the b-axis, the movement of approximately 5 mm was recorded.

In order to measure the settlement of the AMS embankment, four settlement cells were installed underneath the embankment. The settlement was observed during construction and after traffic operation as shown in Figure 7. After the excavation, the data showed swelling behavior of the soft clay. The swelling was overcome by settlement after the air foam mixed soil embankment construction was completed at the end of February 2008. After the embankment was allowed for traffic, the settlement of was regularly monitored. A settlement of approximately 250 mm was observed at SC-2.

The vertical movement at this location mostly occurred after completion of the pavement structure at the end of March 2008.

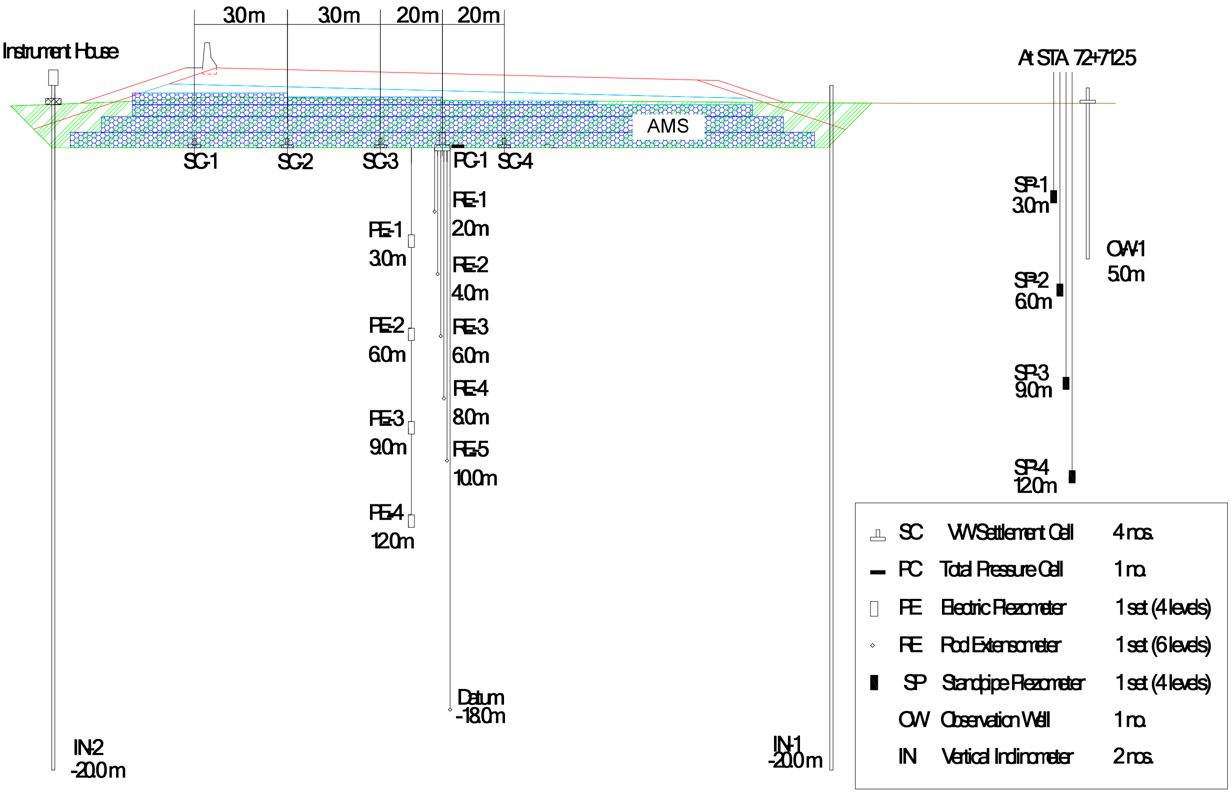
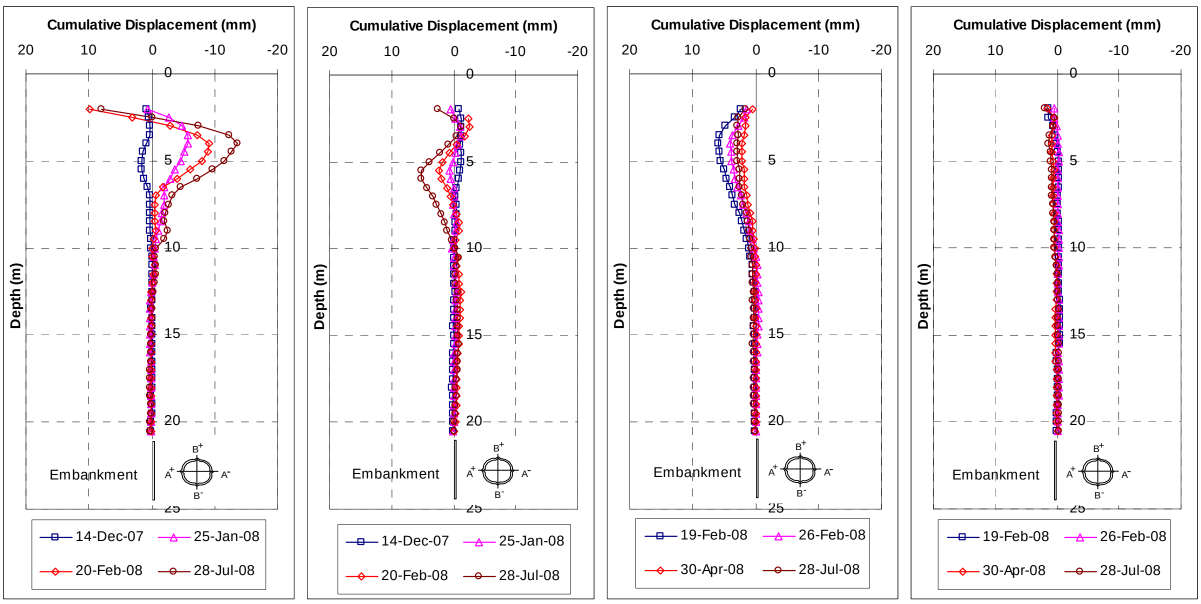


Figure 5. Installed locations of monitoring equipments.



a) IN-1 a-axis   b) IN-1 b-axis   c) IN-2 a-axis   d) IN-2 b-axis

Figure 6. Inclinometer movement.

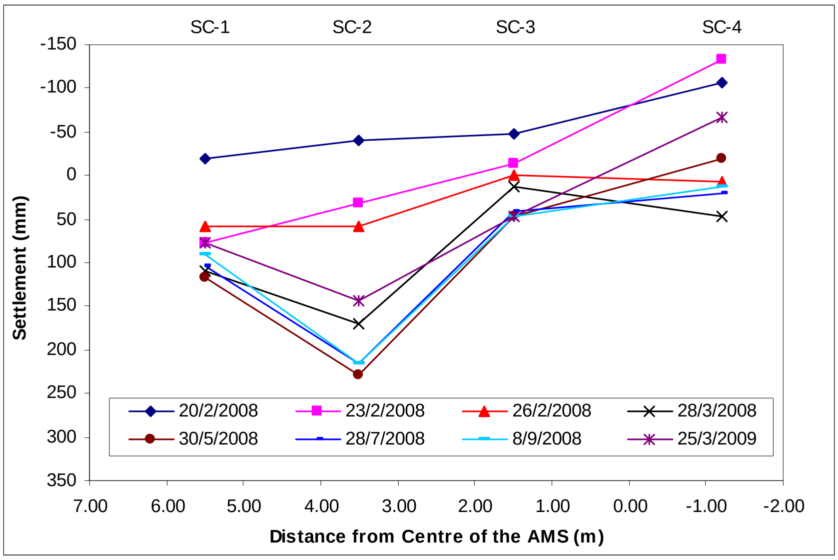


Figure 7. Settlements under the AMS Embankment.

To compare the effectiveness of AMS embankment, the elevations of the stabilized and non-stabilized embankments was surveyed for a comparison of surface settlements. Figure 8 shows the record of differences of surface settlement from initial records of AMS embankment (solid symbols) compared to that of non AMS embankment (open symbols). The data were taken on opposite bridge approach on the same embankment at 6 months and a year after construction completed. After the structure was services for a year, the settlement of the AMS embankment was approximately 50 mm while that of the non-AMS embankment was about 100 mm. Based on the monitoring results, the AMS embankment can reduce vertical settlement by approximately 50%.

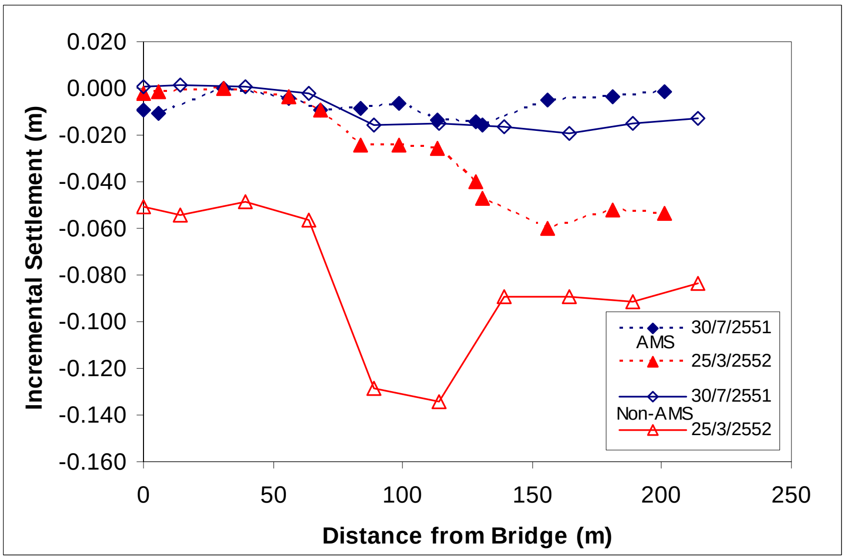


Figure 8. Comparison of Surface Settlements of the AMS Embankment.

6. SUMMARY

Application of AMS for settlement reduction at the bridge approach was used on highway number 35 at the kilometer post of 72+712.5 to 72+775.0. The advantages of AMS for reduction of settlement at the bridge approach can be pointed out as follows. It is light weight material. Therefore, the load due to its own weight is minimized resulting in less settlement in comparison with the conventional embankment. It encourages use of local construction material of the in-situ clay. Highway destruction as the result of highway construction material hauling in and away from the construction site is minimized because the undercut in-situ and subgrade clay can be used in the AMS mixture. The quality control of the mixture is relatively easy by performing tests of unconfined compressive strength, density and flowing ability. The plant mixture can be pumped in the prepared formwork with needless of compaction.

In the study, the unconfined compressive strength of 6 ksc was controlled, which requires the amount of Portland cement of 218 kg/m^3. Short and long term performances of the installed AMS embankment were monitored by the installed geotechnical instrumentations. To date, the monitored results show good performance of the constructed embankment, with very minimal recorded settlement. After the side-by-side comparison of settlements of the AMS and conventionally constructed embankment, the recorded data revealed that about 50% of vertical settlement was reduced. The performance monitoring program is still ongoing to monitor the long term performance of the constructed AMS embankment. With the observed good results of the study, it is expected that the use of AMS would increase safety and driving comfort of road users, expand the service life of road and save highway construction and maintenance budget.

7. ACKNOWLEDGEMENTS

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